Resolution of the Diols of Bicyclo[2.2.1]heptane, Bicyclo[2.2.2]octane and Bicyclo[3.2.1]octane by Enzymic Hydrolysis, and their Absolute Configurations[1]

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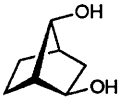
Enzyme (pig liver esterase and lipase from *Aspergillus niger*)-catalysed enantioselective hydrolyses of racemic diacetates, (1*R**,2*S**,4*R**,5*S**)- and (1*R**,2*R**,4*R**,5*R**)-2,5-diacetoxybicyclo[2.2.1]heptanes, (1*R**,2*S**,4*R**,5*S**)-, (1*R**,2*R**,4*R**,5*R**)- and (1*R**,2*R**,4*R**,5*S**)-2,5-diacetoxybicyclo[2.2.2]octanes, (2*R**,3*R**)-2,3-diacetoxybicyclo[2.2.2]octane and (1*R**,2*S**,6*S**,8*R**)- and (1*R**,2*S**,6*S**,8*S**)-2,8-diacetoxybicyclo[3.2.1]octanes gave the corresponding monoacetates and the recovered diacetates in an optically active form. The absolute configurations of products were unequivocally determined by chemical correlation to the corresponding known monoacetates, (2*S*)-(+)-2-acetoxybicyclo[2.2.1]heptane, (2*S*)-(+)-2-acetoxybicyclo[2.2.2]octane and (2*S*)-(+)-2-acetoxybicyclo[3.2.1]octane, and circular dichroism spectra of keto acetates and diketones derived from the hydrolysis products were examined.

Enzymes are widely exploited as chiral catalysts in kinetic resolution and asymmetric synthesis.[2] We have also been interested in the preparation of chiral synthons by enzyme-catalysed reduction, hydrolysis and transesterification, and in the stereochemistry of these enzyme-catalysed reactions.[3] The diols of bicyclo[2.2.1]heptane and bicyclo[2.2.2]octane, with conformationally rigid carbon frameworks, are currently undergoing investigation as chiral ligands, of organometallic catalysts[4] and as chiral subunits for constructing optically active host molecules.[5] In this regard, it was necessary to resolve these diols easily and to confirm their absolute configurations. Although virtually every class of enzymes has been applied synthetically, hydrolytic enzymes are of particular usefulness for the preparation of optically active alcohols. Recently, we resolved bicyclo[2.2.1]heptane-2,7-diols **1** and **2** by enzymic enantioselective hydrolysis of the corresponding diacetates and determined their absolute configurations.[6]



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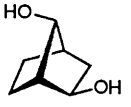

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In this paper, we report kinetic resolutions of bicyclo[2.1.1]heptane-2,5-diols **3** and **11**, bicyclo[2.2.2]octane-2,5-diols **15**, **23** and **29**, bicyclo[2.2.2]octane-2,3-diol **33** and bicyclo[3.2.1]octane-2,8-diols **39** and **48** by pig liver esterase (PLE)- and lipase from *Aspergillus niger* (lipase A)-catalysed enantioselective hydrolysis of the corresponding diacetates, and determination of the absolute configurations of these diols. As we have been studying chiroptical properties of polycyclic compounds, the circular dichroism (CD) spectra of ketones derived from the hydrolysis products are discussed.

Results and Discussion

(1*R**,2*S**,4*R**,5*S**)-Bicyclo[2.2.1]heptane-2,5-diol (*exo,exo*-diol) **3**[7] was stereospecifically prepared by hydroboration–oxidation of bicyclo[2.2.1]hepta-2,5-diene, and reduction of bicyclo[2.2.1]heptane-2,5-dione **10** with $LiAlH(OBu^t)_3$ gave exclusively (1*R**,2*R**,4*R**,5*R**)-bicyclo[2.2.1]heptane-2,5-diol (*endo,endo*-diol) **11**.[7] $LiAlH_4$ reduction of bicyclo[2.2.2]octane-2,5-dione **19** gave a 39:7:54 mixture of (1*R**,2*S**,4*R**,5*S**)-bicyclo[2.2.2]octane-2,5-diol (*exo,exo*-diol) **15**, (1*R**,2*R**,4*R**,5*R**)-bicyclo[2.2.2]octane-2,5-diol (*endo,endo*-diol) **23** and (1*R**,2*R**,4*R**,5*S**)-bicyclo[2.2.2]octane-2,5-diol (*endo,exo*-diol) **29**, which was separated by silica gel chromatography.[8] Hydrolysis of 2,3-epoxybicyclo[2.2.2]octane with methanolic KOH, followed by treatment with acetic anhydride and pyridine, gave a separable 28:56:16 mixture of (2*R**,3*R**)-2,3-diacetoxybicyclo[2.2.2]octane (*trans*-diol) **36**, (1*R**,2*S**,6*S**,8*R**)-2,8-diacetoxybicyclo[3.2.1]octane **43** and (1*R**,2*S**,6*S**,8*S**)-2,8-diacetoxybicyclo[3.2.1]octane **52**.[9]

Enzyme-catalysed hydrolyses of racemic diacetates were performed in 0.1 mol dm^{-3} phosphate buffer solution (pH 8.0) at room temperature and the progress was monitored by GLC. The reaction was terminated at, or close to, 50%-of-hydrolysis point by extraction with methylene dichloride and the products were separated by silica gel chromatography. The enantiomeric excess (ee) values of the products was confirmed by HPLC analysis of the bis(phenylcarbamate)s **4**, **16**, **24**, **30**, **34**, **40** and **49** and bis-(3,5-dichlorobenzoate) **12** which were derived from the corresponding diols (see Schemes 1–5).

Optical resolutions of racemic diacetates were first performed by PLE-catalysed hydrolysis. Conversion of half the initial *endo,endo*-diacetate (±)-**14** into the monoacetate (−)-**13** required 33 h incubation in contrast to 3.5 h for the *exo,exo*-diacetate (±)-**6**. The remarkable difference in the reaction rate between diastereoisomers was observed more distinctly in the hydrolyses of 2,5-diacetoxybicyclo[2.2.2]octanes. The hydrolysis of the *exo,exo*-diacetate (±)-**18** gave the monoacetate (+)-**17** (52%, 21% ee) and the diacetate (−)-**18** (42%, 26% ee) after 4 h incubation. However, in the hydrolysis of the *endo,endo*-diacetate (±)-**26**, the diol (−)-**23** (7%, 36% ee), the monoacetate (+)-**25**) (29%, 84% ee) and the recovered diacetate (−)-**26** (40%, 66% ee) were isolated from the product after about 9 days incubation. In the cases of PLE-catalysed hydrolyses of diacetates of bicyclic compounds mentioned above, the rates of hydrolyses of *exo,exo*-diacetates were higher than those observed with the corresponding *endo,endo*-diacetates. As deduced from the results, the hydrolysis of the *endo,exo*-diacetate (±)-**32** proceeded at a moderate speed and highly regioselectively to yield the monoacetate (+)-**31** (40%, 17% ee) having an *exo*-hydroxy group, and the diacetate (−)-**32** (40%, 17% ee), and the monoacetate having the *endo*-hydroxy group was not found in the product. The hydrolysis of the *trans*-diacetate (±)-**36** proceeded rapidly and with high enantioselectivity to yield the monoacetate (+)-**35** (48%, 82% ee) and

Table 1 PLE-catalysed enantioselective hydrolysis of racemic diacetates

Entry	Substrate	Time (*t*/h)	Products (% isolated yield)	ee/%
1	(±)-**6**	3.5	(2*S*,5*S*)-(+)-**5** (58)	10
			(2*R*,5*R*)-(−)-**6** (37)	13
2	(±)-**14**	33	(2*S*,5*S*)-(−)-**13** (40)	19
			(2*R*,5*R*)-(+)-**14** (50)	15
3	(±)-**18**	4	(2*S*,5*S*)-(+)-**17** (52)	21
			(2*R*,5*R*)-(−)-**18** (42)	26
4	(±)-**26**	211	(2*R*,5*R*)-(−)-**23** (7)	36
			(2*S*,5*S*)-(+)-**25** (29)	84
			(2*R*,5*R*)-(−)-**26** (40)	66
5	(±)-**32**	48	(2*R*,5*S*)-(+)-**31** (40)	17
			(2*S*,5*R*)-(−)-**32** (40)	17
6	(±)-**36**	4.5	(2*R*,3*R*)-(+)-**35** (48)	82
			(2*S*,3*S*)-(+)-**36** (32)	85
7	(±)-**43**	205	(2*R*,8*S*)-(+)-**41** (29)	87
			(2*S*,8*R*)-(+)-**42** (22)	85
			(2*S*,8*R*)-(+)-**43** (40)	8
8	(±)-**52**	76	(2*R*,8*R*)-(+)-**50** (28)	87
			(2*S*,8*S*)-(+)-**52** (44)	48

Table 2 Lipase A-catalysed enantioselective hydrolysis of racemic diacetates

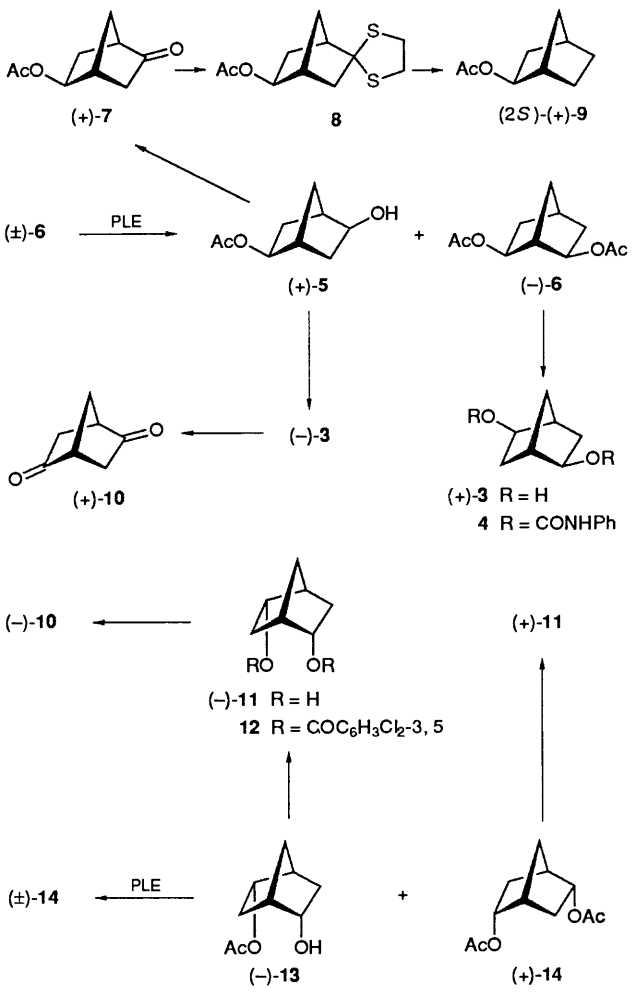
Entry	Substrate	Time (*t*/h)	Products (% isolated yield))	ee/%
1	(±)-**36**	9.5	(2*S*,3*S*)-(−)-**35** (35)	80
			(2*R*,3*R*)-(−)-**36** (34)	74
2	(±)-**43**	24	(2*S*,8*R*)-(−)-**41** (22)	82
			(2*R*,8*S*)-(−)-**42** (30)	68
			(2*S*,8*R*)-(+)-**43** (30)	12
3	(±)-**52**	20	(2*S*,8*S*)-(−)-**50** (23)	85
			(2*S*,8*S*)-(+)-**51** (16)	58
			(2*R*,8*R*)-(−)-**52** (46)	58

the diacetate (+)-**36** (32%, 85% ee) after 4.5 h incubation. In the case of hydrolysis of the *endo,endo*-diacetate (±)-**43**, the reaction rate was lower than that observed with the *endo,exo*-diacetate (±)-**52**, but two monoacetates with high optical purity were formed. (+)-8-Acetoxy-2-hydroxybicyclo[3.2.1]octane **41** (29%, 87% ee) and (+)-2-acetoxy-8-hydroxybicyclo[3.2.1]-octane **42** (22%, 85% ee), which were derived from (2*R*,8*S*)-(−)-**43** and (2*S*,8*R*)-(+)-**43**, respectively, were isolated and hence, the ee-value of the recovered diacetate (+)-**43** (40%) was low (8% ee). The hydrolysis of *endo,exo*-diacetate (±)-**52** proceeded regiospecifically to yield (+)-8-acetoxy-2-hydroxybicyclo[3.2.1]octane **50** (28%, 87% ee) and the diacetate (+)-**52** (44%, 48% ee), and the monoacetate **51** was not found in the PLE-catalysed hydrolysis product. The results of PLE-catalysed hydrolyses of racemic diacetates are summarized in Table 1.

The hydrolysis of the *trans*-diacetate (±)-**36** with lipase A showed a reversal of selectivity and gave (−)-**35** (35%, 80% ee) and (−)-**36** (34%, 74% ee). In the cases of hydrolyses of 2,8-diacetoxybicyclo[3.2.1]octanes with lipase A, markedly different behaviour between two diastereoisomers (±)-**43** and (±)-**52** were observed in the stereospecificity. The hydrolysis of the *endo,endo*-diacetate (±)-**43**, the enantioselectivity of which was reversed compared with that of PLE-catalysed hydrolysis, proceeded stereospecifically to give the monoacetates (2*S*,8*R*)-(−)-**41** (22%, 82% ee) and (2*R*,8*S*)-(−)-**42** (30%, 68% ee) together with the diacetate (+)-**43** (30%) of low optical purity (12% ee). On the other hand, in the case of the hydrolysis of the *endo,exo*-diacetate (±)-**52**, two monoacetates (2*S*,8*S*)-(−)-**50** (25%, 85% ee) and (2*S*,8*S*)-(+)-**51** (17%, 58% ee) were derived from the same diacetate (2*S*,8*S*)-(+)-**52** and hence, the recovered diacetate (2*R*,8*R*)-(−)-**52** (50%) was obtained with a moderate optical purity (58% ee). The results of hydrolyses of racemic diacetates with lipase A are given in Table 2.

Our next task was the assignment of the absolute configurations of optically active products and this was achieved by chemical correlation with known compounds.

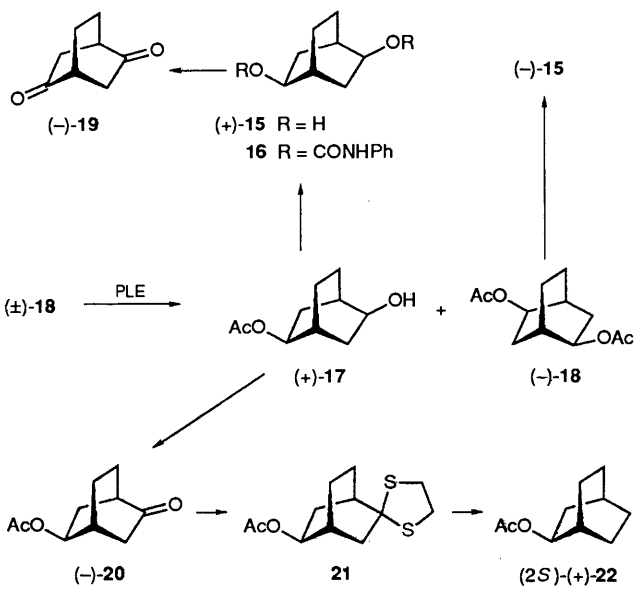
All derivatives of bicyclo[2.2.1]heptanes were correlated with (2*S*)-(+)-2-acetoxybicyclo[2.2.1]heptane **9**[10] as shown in Scheme 1. Oxidation of the monoacetate (+)-**5** with Jones



Scheme 1

reagent gave the keto acetate (+)-7, which was converted into the dithioketal **8**, desulfurisation of which gave compound (2*S*)-(+)-**9**. The correlation led us to assign the (2*S*,5*S*)-configuration to (+)-**5** and the (1*R*,4*R*,5*S*)-configuration to compound (+)-7, and $LiAlH_4$ reduction of compound (+)-**5** to yield the diol (−)-**3** allowed us to assign the (2*S*,5*S*)-configuration to (−)-**3**. The assignment of the diacetate (2*R*,5*R*)-(−)-**6** was achieved by its $LiAlH_4$ reduction of (2*R*,5*R*)-(+)-**3**. The diketone **10** served as a relay compound for the configurational correlation of the *exo,exo*-diol **3** and the *endo,endo*-diol **11**. Oxidation of (2*S*,5*S*)-(−)-**3** with Jones reagent afforded (1*R*,4*R*)-(+)-**10**; similarly, oxidation of the diol (−)-**11**, which was prepared by $LiAlH_4$ reduction of the monoacetate (−)-**13**, gave the dione (−)-**10**. The results led us to assign the (2*S*,5*S*)-configuration of the monoacetate (−)-**13** as well as to diol (−)-**11**, and reduction of the diacetate (+)-**14** gave (2*R*,5*R*)-(+)-**11**.

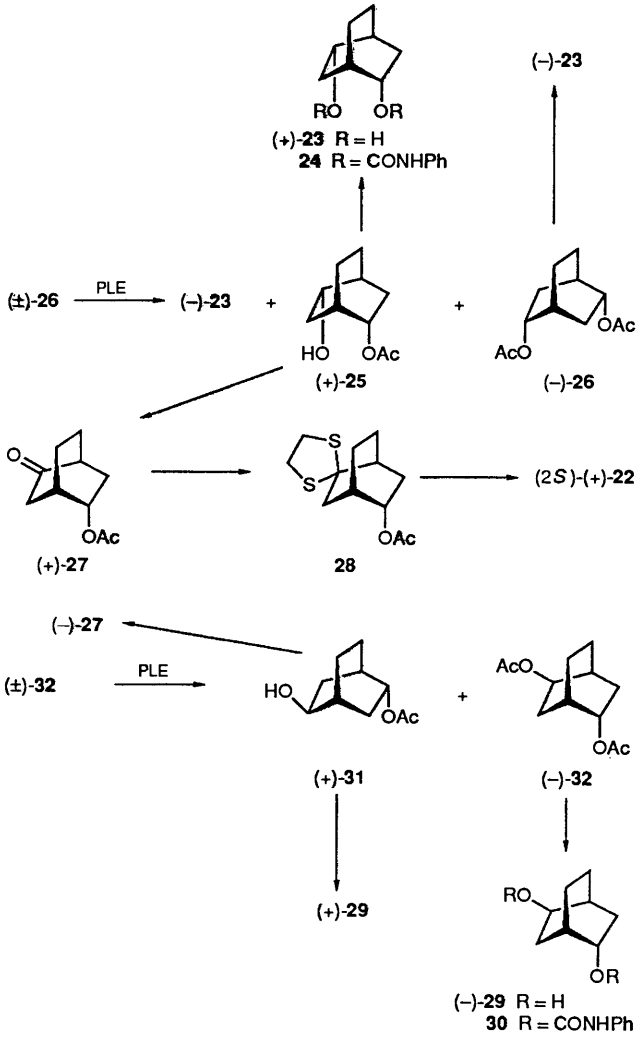
The absolute configurations of all bicyclo[2.2.2]octane derivatives were determined on the basis of the known (2*S*)-(+)-



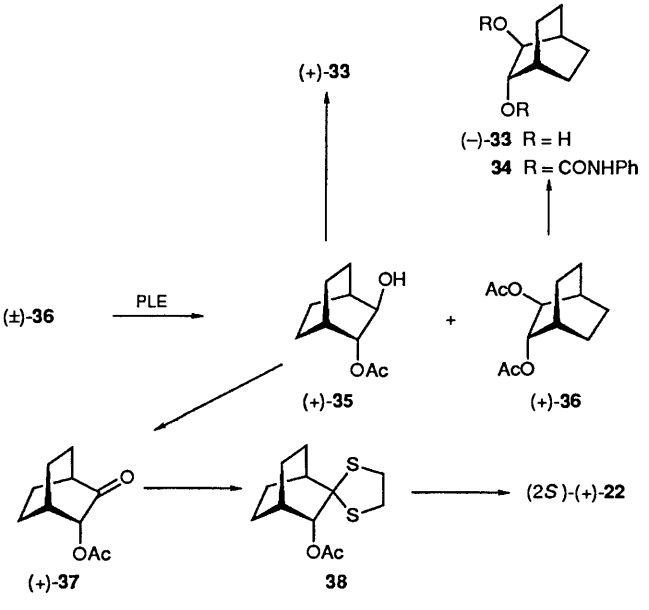
Scheme 2

2-acetoxybicyclo[2.2.2]octane **22** (see Scheme 2).[11] The monoacetate (+)-**17** was assigned the (2*S*,5*S*)-configuration by conversion of (+)-**17** into the monoacetate (2*S*)-(+)-**22** *via* the keto acetate (−)-**20** and the ketal **21**. $LiAlH_4$ reductions of the monoacetate (+)-**17** and the diacetate (−)-**18** afforded the diol (+)-**15** and (−)-**15**, respectively. These conversions assigned the (2*S*,5*S*)-configuration to the diol (+)-**15** and the (2*R*,5*R*)-configuration to compounds (−)-**15** and (−)-**18**.

The absolute configurations of all derivatives of *endo,endo*- and *endo,exo*-2,5-disubstituted bicyclo[2.2.2]octanes were confirmed on the basis of the keto acetate (1*S*,4*S*,5*S*)-(+)-**27**, which was also determined by its conversion into the acetate (2*S*)-(+)-**22** *via* the ketal **28** (Scheme 3). Conversions of the monoacetate (+)-**25** to give the diol (+)-**23** and keto acetate (+)-**27** assigned the (2*S*,5*S*)-configuration to the diol (+)-**23** as well as to the acetate (+)-**25**, and reduction of the diacetate (−)-**26** gave the diol (2*R*,5*R*)-(−)-**23**. While half-hydrolysis of the *endo,exo*-diacetate (±)-**32** could give two monoacetates, the monoacetate (+)-**31** was isolated as the sole hydrolysed product and its structure and absolute configuration were unambiguously determined by its conversion into the keto acetate (−)-**27**. Oxidation of the monoacetate (+)-**31** to yield compound (1*R*,4*R*.5*R*)-(−)-**27** showed that the monoacetate (+)-**31** has the *endo*-acetoxy group together with the (2*R*,5*S*)-configuration. The absolute configuration of the diol (+)-**29** (2*R*,5*S*) was determined by reduction of the diacetate (+)-**31** to the diol (+)-**29**, and the diacetate (−)-**32** was reduced to (2*S*,5*R*)-(−)-**29**. Similarly, on the basis of the monoacetate (2*S*)-(+)-**22**, the (2*R*,3*R*)-, (2*R*,3*R*)-, (2*S*,3*S*)- and (3*R*)-configurations were assigned to the diol (+)-**33**, the monoacetate (+)-**35**, the diacetate (+)-**36** and the keto acetate (+)-**37**, respectively (see Scheme 4).

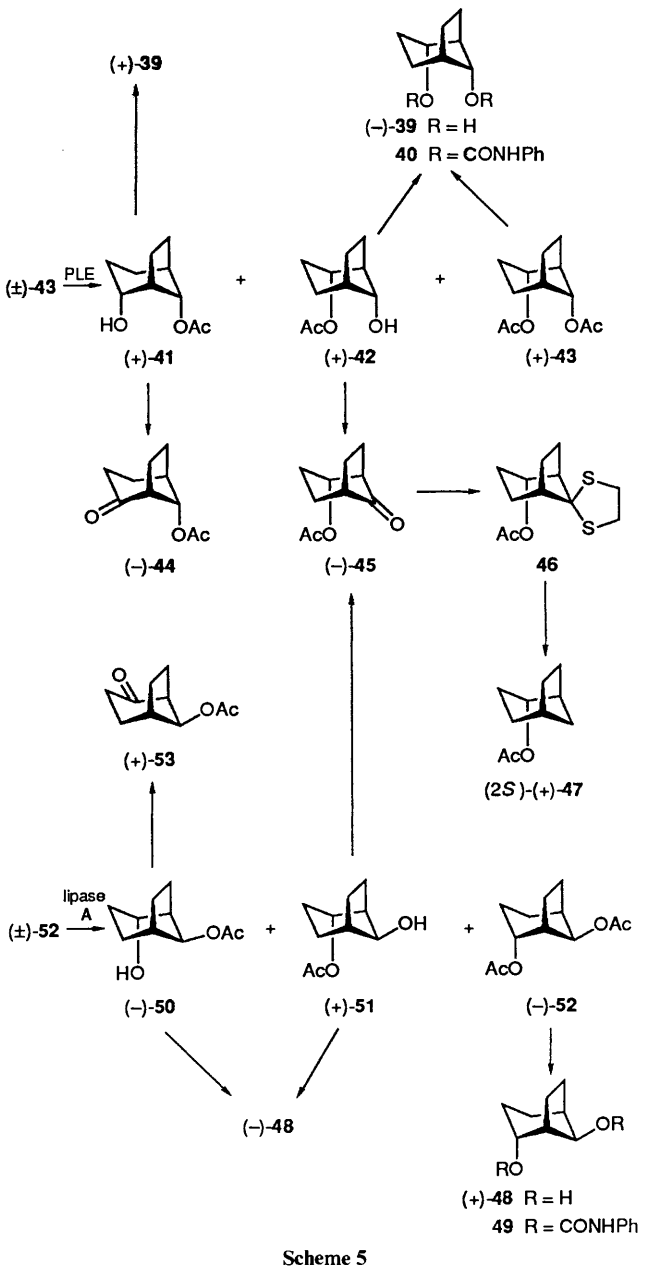


Scheme 3



Scheme 4

Hydrolysis of the *endo,endo*-diacetate (±)-**43** gave two monoacetates, (+)-**41** and (+)-**42**, oxidation of which yielded the keto acetates (−)-**44** and (−)-**45**, respectively. The keto acetate (−)-**45** was converted into (2*S*)-(+)-2-acetoxybicyclo[3.2.1]octane **47**[12] *via* the ketal **46** and the sequence of conversions assigned the structures (2*S*,8*R*)-2-acetoxybicyclo[3.2.1]octan-8-ol and (1*R*,2*S*,5*S*)-2-acetoxybicyclo[3.2.1]octan-8-one, respectively, to (+)-**42** and (−)-**45**. Therefore, the other monoacetate (+)-**41** and the keto acetate (−)-**44** were unequivocally determined to be 8-acetoxybicyclo[3.2.1]octan-2-ol and 8-acetoxybicyclo[3.2.1]octan-2-one, respectively. $LiAlH_4$ reductions of the acetates (+)-**42** and (+)-**43** gave the same diol, (−)-**39**, whose absolute configuration was assigned to be 2*S*,8*R*, and the absolute configurations of (+)-**41** as 2*R*,8*S* and of (−)-**44** as 1*R*, 5*R*, 8*S* were determined by conversion



Scheme 5

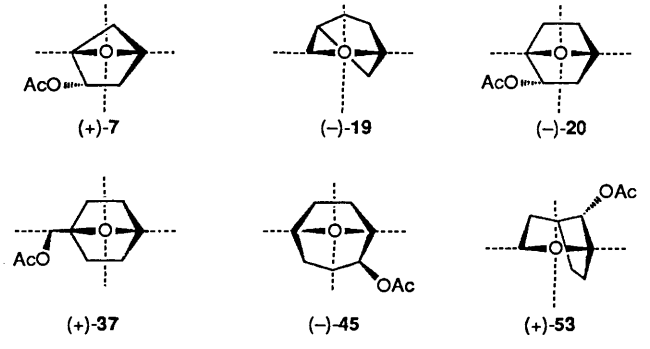


Fig. 1 Octant projection formulae of ketones (+)-7, (−)-19, (−)-20, (+)-37), (−)-45 and (+)-53

of the monoacetate (+)-**41** into the diol (+)-(2*R*,8*S*)-**39** (see Scheme 5).

The monoacetates (−)-**50** and (+)-**51**, obtained by lipase A-catalysed hydrolysis of the diacetate (±)-**52**, were oxidized to give the keto acetate (+)-**53** and (1*R*,2*S*.5*S*)-(−)-**45**, respectively. The conversions revealed that compound (+)-**51** has the hydroxy group located at C-8 and the (2*S*,8*S*)-configuration, and that its isomer (−)-**50** has the hydroxy group located at C-2. The reductions of monoacetates (−)-**50** and (2*S*,8*S*)-(+)-**51** provided the same diol (−)-**48**, the absolute configuration of which was confirmed to be 2*S*,8*S*, and the absolute configuration of the monoacetate (−)-**50** as 2*S*,8*S* and of the keto acetate (+)-**53** as 1*S*,5*S*,8*S* were also determined by these correlations. The absolute configuration of the diacetate (−)-**52** as 2*R*,8*R* was confirmed by its reduction to the diol (+)-**48**.

The octant rule for ketones is a significant and successful attempt to correlate their absolute configuration with their experimental properties. Analyses of the CD spectra exhibited by various ketones of 'cage-shaped' compounds so far examined by our group[13] indicated that the sign of the CD curve due to the n–π* transition can be predicted by applying the octant rule to the 'outer ring'[14] in the projection formula. Application of the generalization to projection formulas shown in Fig. 1 predicts that the ketoacetates (+)-**7** and (+)-**53** would give a negative and a positive Cotton effect, respectively, which were found to be in agreement with our observations. In the case of the projection formula of compound (−)-**20**, the outer ring is achiral and the lone disymmetric acetoxy perturber lies in (−)-back octant. Accordingly a negative Cotton effect exhibited by compound (−)-**20** is predicted by applying the octant rule to this projection formula. Similarly, a positive and a negative Cotton effect exhibited by compounds (+)-**27** and (−)-**44**, respectively, are predicted by applying the octant rule to their projection formulae. In one of our recent papers[6] we have described how (1*R*,2*S*,4*S*)-(−)-2-acetoxybicyclo[2.2.1]heptan-7-one, exhibiting a negative Cotton effect in its CD spectrum, showed an apparently 'anti-octant' effect, but the lone disymmetric acetoxy perturber in this molecule lies in the (−)-front octant and not in the (+)-back octant in its projection formula. Similarly, we concluded that the lone disymmetric acetoxy perturbers of compounds (+)-**37** and (−)-**45** lie in the (+)-front octant and in the (−)-front octant in their projection formulae, respectively.

Applying the octant rule to the outer ring in projection formulae of the diketones (+)-**10** and (−)-**19** having two homotopic carbonyl groups predicts negative Cotton effects in their CD spectra, which were found to be consistent with our observations.

As mentioned above, the diols of bicyclo[2.2.1]heptanes, bicyclo[2.2.2]octanes and bicyclo[3.2.1]octanes were easily resolved by enzymic hydrolysis of the corresponding diacetates and their absolute configurations were established.

Experimental

General Procedure.—^{1}H NMR spectra were obtained on a JASCO JNM-MH-100 spectrometer for solutions in $CDCl_3$ with $SiMe_4$ as internal standard. *J*-Values are given in Hz. Mass spectroscopic analyses were carried out on a JEOL-DX-303-HF spectrometer. Elemental analyses were carried out on a Yanagimoto CHN-Coder, Type 2. Optical rotations were measured using a JASCO DIP-40 polarimeter. $[\alpha]_D$-Values are given in units of 10^{-1} deg cm^2 g^{-1}. CD spectra were obtained on a JASCO J-500 spectropolarimeter for solutions in 2,2,4-trimethylpentane. Gas chromatography was performed on a Simazu GS 8A chromatograph using an SE-52 on Uniport HP, 2 m × 2.6 mm, column and a PEG 20M on Chromosorb W, 2 m × 2.6 mmol, column. HPLC analyses were carried out on a Simazu LC-6A chromatograph using a chiral column of Opti-Pak XC (Waters), 250 mm × 4.6 mm.

PLE (Boehringer Mannheim Gmbh Co.) and lipase A (Amano pharmaceutical Co.) were used as received without further purification.

Preparation of the Diacetates (±)-**36**, (±)-**43** *and* (±)-**52**.—To a solution of bicyclo[2.2.2]oct-2-ene (5.00 g, 0.0463 mol), 90% formic acid, and diethyl ether (30 cm^3) at room temp. was added 30% aq. hydrogen peroxide (10 cm^3) and then the mixture was stirred for 4 h at 50–55 °C. After the reaction mixture had been concentrated at 40–50 °C under reduced pressure, 10% methanolic KOH (50 cm^3) was added to the residue, and the mixture was stirred for 12 h at room temperature. Usual work-up gave a mixture of diols (4.51 g) as a solid, which was treated with acetic anhydride (12.0 g) and pyridine (30 cm^3) at room temperature. Usual work-up gave a 28:56:16 mixture of diacetates **36**, **43** and **52**, which was separated on silica gel chromatography (benzene–diethyl ether 95/5–9/1 as eluent).

Diacetate (±)-**36**: b.p. 128–130 °C (10 mmHg); δ_H 1.2–1.9 (10 H, m, CH and CH_2), 2.06 (6 H, s, Me) and 4.08 (2 H, t, *J* 1, 2- and 3-H) (Found: C, 63.75; H, 8.0. $C_{12}H_{18}O_4$ requires C, 63.70; H, 8.02%).

Diacetate (±)-**43**: b.p. 166–168 °C (18 mmHg); δ_H 1.1–2.7 (10 H, m, CH and CH_2), 2.02 (3 H, s, Me), 2.11 (3 H, s, Me), 4.62 (1 H, t, *J* 5, 8-H) and 4.78 (1 H, m, 2-H) (Found: C, 63.8; H, 8.0%).

Diacetate (±)-**52**: b.p. 140 °C (10 mmHg); δ_H 1.3–2.4 (10 H, m, CH and CH_2), 2.01 (3 H, s, Me), 2.07 (3 H, s, Me), 4.80 (1 H, br s, CH) and 5.08 (1 H, s, CH) (Found: C, 63.8; H, 8.0%).

(±)-exo,exo-2,5-*Diacetoxybicyclo*[2.2.1]*heptane* **6** (5.77 g, 92%) from (±)-**3**[7] (3.77 g), b.p. 124–125 °C (2 mmHg) (Found: C, 62.1; H, 7.6. $C_{11}H_{16}O_4$ requires C, 62.25; H, 7.60%).

(±)-endo,endo-2,5-*Diacetoxybicyclo*[2.2.1]*heptane* **14** (1.46 g, 88%) from (±)-**11**[7] (1.00 g), b.p. 130–132 °C (5 mmHg) (Found: C, 62.1; H, 7.55%).

(±)-exo,exo-2,5-*Diacetoxybicyclo*[2.2.2]*octane* **18** (1.38 g, 70%) from (±)-**15**[8] (588 mg), b.p. 130 °C (5 mmHg); δ_H 1.3–1.6 (4 H, m, CH_2), 1.7–1.9 (6 H, m, CH and CH_2), 2.04 (6 H, s, Me) and 4.7–4.9 (2 H, m, 2- and 5-H) (Found: C, 63.7; H, 8.0%).

(±)-endo,endo-2,5-*Diacetoxybicyclo*[2.2.2]*octane* **26** (1.02 g, 68%) from (±)-**23**[8] (937 mg), b.p. 132 °C (8 mmHg); δ_H 1.4–1.6 (4 H, m, CH_2), 1.7–2.0 (6 H, m, CH and CH_2), 2.04 (6 H, s, Me) and 4.7–4.9 (2 H, m, 2- and 5-H) (Found: C, 63.7; H, 8.0. $C_{12}H_{18}O_4$ requires C, 63.70; H, 8.02%).

(±)-endo,exo-2,5-*Diacetoxybicyclo*[2.2.2]*octane* **32** (2.52 g, 89%) from (±)-**29**[8] (1.77 g), b.p. 135 °C (8 mmHg); δ_H 1.1–2.4 (10 H, m, CH and CH_2), 2.04 (3 H, s, Me), 2.05 (3 H, s, Me), 4.7–5.0 (2 H, m, 2- and 5-H) (Found: C, 63.7; H, 8.0%).

Representative Procedure for PLE-catalysed Hydrolyses of Diacetates.—Hydrolysis of (±)-exo,exo-2,5-*diacetoxybicyclo*[2.2.2]*octane* **18** (*Table* 1, *entry* 3). A mixture of the diacetate (±)-**18** (600 mg, 2.65 mmol) and 0.1 mol dm^{-3} phosphate buffer solution (pH 6.9; 1.8 dm^3) was vigorously stirred and PLE (600 mm^3) was added to the mixture, which was then stirred for 4 h at room temperature and extracted with methylene dichloride. After the extract had been dried ($MgSO_4$) and concentrated, silica gel chromatography of the residue provided the diacetate (−)-**18** (benzene–1% diethyl ether as eluent) (253 mg, 42%); $[\alpha]_D^{25}$ −4.37 (*c* 1.01, $CHCl_3$) and monoacetate (+)-**17** (benzene–10%-diethyl ether) (253 mg, 52%); $[\alpha]_D^{26}$ +6.99 (*c* 1.10, $CHCl_3$); δ_H 1.2–2.1 (10 H, m, CH and CH_2), 2.04 (3 H, s, Me), 2.12 (1 H, s, OH), 3.8–4.0 (1 H, m, CH) and 4.7–4.9 (1 H, m, CH); *m/z* 184 (M^+).

Hydrolysis of (±)-exo,exo-2,5-*diacetoxybicyclo*[2.2.1]*heptane* **6** (*Table* 1, *entry* 1). The monoacetate (+)-**5**; 58%; oil; $[\alpha]_D^{24}$ +0.81 (*c* 2.40, $CHCl_3$); optically active substrate (−)-**6**; 37%; $[\alpha]_D^{24}$ −1.43 (*c* 1.01, $CHCl_3$).

Hydrolysis of (±)-endo,endo-2,5-*diacetoxybicyclo*[2.2.2]*heptane* **14** (*Table* 1, *entry* 2). The monoacetate (−)-**13**; 44%; $[\alpha]_D^{26}$ −5.21 (*c* 3.26, $CHCl_3$); optically active substrate (+)-**14**; 50%; $[\alpha]_D^{26}$ +5.60 (*c* 3.20, $CHCl_3$).

Hydrolysis of (±)-endo-endo-2,5-*diacetoxybicyclo*[2.2.2]*octane* **16** (*Table* 1, *entry* 4). The diol (−)-**23**; 7%; $[\alpha]_D^{25}$ −19.4 (*c* 1.22, $CHCl_3$); the monoacetate (+)-**25**; 29%; $[\alpha]_D^{24}$ +19.9 (*c* 1.50, $CHCl_3$); δ_H 1.4–2.0 (10 H, m, CH and CH_2), 2.06 (3 H, s, Me), 1.91 (1 H, s, OH), 3.8–4.0 (1 H, m, CH) and 4.7–4.9 (1 H, m, CH); the optically active substrate (−)-**26**; 40%; $[\alpha]_D^{26}$ −23.3 (*c* 1.25, $CHCl_3$).

Hydrolysis of (±)-endo,exo-2,5-*diacetoxybicyclo*[2.2.2]*octane* **32** (*Table* 1, *entry* 5). The monoacetate (+)-**31**; 40%; $[\alpha]_D^{26}$ +1.23 (*c* 1.21, $CHCl_3$); δ_H 1.1–2.3 (10 H, m, CH and CH_2), 1.80 (1 H, s, OH), 2.02 (3 H, s, Me), 3.8–4.0 (1 H, m, CH) and 4.6–4.9 (1 H, m, CH); *m/z* 184 (M^+); the optically active substrate (−)-**32**; 40%; $[\alpha]_D^{24}$ −1.48 (*c* 1.29, $CHCl_3$).

Hydrolysis of (±)-trans-2,3-*diacetoxybicyclo*[2.2.2]*octane* **36** (*Table* 1, *entry* 6). The monoacetate (+)-**35**; 48%; $[\alpha]_D^{24}$ +67.4 (*c* 1.33, $CHCl_3$); the optically active substrate (+)-**36**; 32%; $[\alpha]_D^{24}$ +14.6 (*c* 1.21, $CHCl_3$).

Hydrolysis of (±)-endo-endo-2,8-*diacetoxybicyclo*[3.2.1]*octane* **43** (*Table* 1, *entry* 7). The monoacetate (+)-**41**; 29%; $[\alpha]_D^{24}$ +52.8 ($CHCl_3$); δ_H 1.1–2.0 (8 H, m, CH_2), 2.14 (1 H, s, Me), 2.32 (2 H, br s, CH), 3.10 (1 H, br s, OH), 3.68 (1 H, br s, 2-H), 4.88 (1 H, t, *J* 5, 8-H); the monoacetate (+)-**42**; 22%; $[\alpha]_D^{24}$ +45.2° (*c* 1.23, $CHCl_3$); δ_H 1.1–2.0 (8 H, m, CH_2), 2.10 (3 H, s, Me), 2.32 (2 H, br s, CH), 3.20 (1 H, br s, OH), 3.88 (1 H, br s, 2-H) and 4.92 (1 H, t, *J* 5, 8-H); the optically active substrate (+)-**43**; $[\alpha]_D^{25}$ +5.40 (*c* 1.32, $CHCl_3$).

Hydrolysis of endo,exo-2,8-*diacetoxybicyclo*[3.2.1]*octane* **52** (*Table* 1, *entry* 8). The monoacetate (+)-**50**; 28%; $[\alpha]_D^{25}$ +23.7 (*c* 1.40, $CHCl_3$); δ_H 1.2–2.0 (8 H, m, CH_2), 2.01 (3 H, s, Me), 2.27 (3 H, br s, CH and OH), 3.8–4.0 (1 H, m, 2-H) and 5.16 (1 H, s, 8-H); optically active substrate (+)-**52**; 44%; $[\alpha]_D^{26}$ +4.07 (*c* 1.85, $CHCl_3$).

Representative Procedure for Lipase A-catalysed Hydrolyses of Diacetates.—Hydrolysis of compound (±)-**52** (*Table* 2, *entry* 3).—To a mixture of compound (±)-**52** (490 mg, 2.17 mmol) and 0.1 mol dm^{-3} phosphate buffer solution (pH 6.9; 1.5 dm^3) was added lipase A (1.00 g) and the mixture was stirred for 24 h at 30 °C. After the same work-up as described for the hydrolysis with PLE, silica gel chromatography of the residue gave the optically active substrate (−)-**52** (benzene–2% diethyl ether as eluent) (225 mg, 50%; $[\alpha]_D^{24}$ −3.36 (*c* 1.50, $CHCl_3$), the monoacetate (−)-**50** (benzene-5% diethyl ether) (65 mg, 17%); $[\alpha]_D^{26}$ +0.74 (*c* 1.05, $CHCl_3$) and the monoacetate (+)-**51** (benzene–10% diethyl ether) (92 mg, 25%); $[\alpha]_D^{26}$ +0.74 (*c* 3.50, $CHCl_3$); δ_H 1.1–2.2 (10 H, m, CH and CH_2), 2.02 (3 H, s, Me), 2.27 (3 H, br s, CH and OH), 3.8–4.0 (1 H, m, 2-H) and 5.16 (1 H, s, 8-H).

Hydrolysis of compound (±)-**36** (*Table* 2, *entry* 1). The monoacetate (−)-**35**; 35%; $[\alpha]_D^{24}$ −65.3 (*c* 1.20, $CHCl_3$); optically active substrate (−)-**36**; 34%; $[\alpha]_D^{25}$ −12.2 (*c* 2.20, $CHCl_3$).

Hydrolysis of (±)-**43** (*Table* 2, *entry* 2). The monoacetate (−)-**41**; 17%; $[\alpha]_D^{26}$ −52.1 (*c* 1.53, $CHCl_3$); monoacetate (−)-**42**; 25%; $[\alpha]_D^{25}$ −41.9 (*c* 2.20, $CHCl_3$); the optically active substrate (+)-**43**; 30%; $[\alpha]_D^{24}$ +8.58 (*c* 2.52, $CHCl_3$).

Representative Procedure for Oxidation of Monoacetates. Oxidation of Compound (+)-**5**.—To an ice-cooled solution of compound (+)-**5**, $[\alpha]_D$ +0.81 ($CHCl_3$) (373 mg, 2.19 mmol) in acetone (50 cm^3) was slowly added an excess of Jones reagent and the mixture was stirred for 2 h with ice-cooling and then for further 1.5 h at room temperature. After a small amount of propan-2-ol had been added to the reaction mixture, the mixture was stirred for 1 h. The inorganic pasty cake was removed by decantation, and the solution was concentrated under reduced pressure. The residue was diluted with water and extracted with diethyl ether. After usual work-up, silica gel chromatography of the product gave the ketone (1R,4R,5S)-(+)-**7** (307 mg, 83%) as a solid, which was not further

recrystallized to avoid influence on its optical purity, $[\alpha]_D^{25}$ +1.84 (*c* 2.05, $CHCl_3$); [θ] −1.49 × 10^2 (295sh), −1.92 × 10^2 (305) and −1.37 × 10^2 (316); ν_{max}/cm^{-1} 1740, 1250 and 1050 (Found: C, 64.1; H, 7.1. $C_9H_{12}O_3$ requires C, 64.27; H, 7.19%). The following keto acetates were similarly prepared.

(1R,4R,5S)-(−)-5-*Acetoxybicyclo*[2.2.2]*octan*-2-*one* **20** (142 mg, 69%) from the monoacetate (+)-**17**, $[\alpha]_D$ +6.99 ($CHCl_3$) (207 mg); $[\alpha]_D^{24}$ −0.38 (*c* 3.50, $CHCl_3$); [θ] −8.50 × 10 (289sh), 9.47 × 10 (296), −7.54 × 10 (305) and −3.19 × 10 (315sh); ν_{max}/cm^{-1} 1730, 1250, 1210 and 1020; δ_H 1.4–2.4 (10 H, m, CH and CH_2), 2.08 (3 H, s, Me) and 4.8–5.1 (1 H, m, 5-H) (Found: C, 65.8; H, 7.7. $C_{10}H_{14}O_3$ requires C, 65.91; H, 7.74%).

(1S,4S,5S)-(+)-5-*Acetoxybicyclo*[2.2.2]*octan*-2-*one* **27** (165 mg, 93%) from the monoacetate (+)-**25**, $[\alpha]_D$ +19.9 ($CHCl_3$) (180 mg); $[\alpha]_D^{25}$ +19.9 (*c* 2.02, $CHCl_3$); [θ] +56.4 × 10^2 (287sh), +6.38 × 10^2 (296), +5.15 × 10^2 (306) and + 2.27 × 10^2 (318sh); ν_{max}/cm^{-1} 1730, 1250, 1235 and 1025; δ_H 1.6–2.6 (10 H, m, CH and CH_2), 2.06 (3 H, s, Me) and 4.9–5.1 (1 H, m, 2-H) (Found: C, 65.9; H, 7.7%).

(1*R*,4*R*,5*R*)-(−)-5-Acetoxybicyclo[2.2.2]octan-2-one **27** (154 mg, 78%) from the monoacetate (+)-**31**, $[\alpha]_D$ +1.25 ($CHCl_3$) (200 mg); $[\alpha]_D^{25}$ −4.33 (*c* 2.25, $CHCl_3$).

(3R)-(+)-3-*Acetoxybicyclo*[2.2.2]*octan*-2-*one* **37** (180 mg, 77%) from the monoacetate (+)-**35**, $[\alpha]_D$ +67.4 ($CHCl_3$) (237 mg); $[\alpha]_D^{27}$ +95.1 (*c* 1.85, $CHCl_3$); [θ] +3.83 × 10^3 (294); ν_{max}/cm^{-1} 1740, 1720, 1240 and 1055 (Found: C, 65.9; H, 7.7%).

(1R,5R,8S)-(−)-8-*Acetoxybicyclo*[3.2.1]*octan*-2-*one* **44** (72 mg, 71%) from the monoacetate (+)-**41**, $[\alpha]_D$ +52.8 ($CHCl_3$) (102 mg); $[\alpha]_D^{24}$ −100.4 (*c* 1.28, $CHCl_3$); [θ] −3.62 × 10^3 (285sh), −4.41 × 10^3 (294), −4.16 × 10^3 (304) and −2.19 × 10^3 (314); ν_{max}/cm^{-1} 1735, 1250, 1240, 1065 and 1045; δ_H 1.6–2.6 (9 H, m, 5-H and CH_2), 2.04 (3 H, s, Me), 2.80 (1 H, t, *J* 4.3, 1-H) and 5.14 (1 H, t, *J* 5.0, 8-H) (Found: C, 65.8; H, 7.7%).

(1R,2S,5S)-(−)-2-*Acetoxybicyclo*[3.2.1]*octan*-8-*one* **45** (61 mg, 69%) from the monoacetate (+)-**42**, $[\alpha]_D$ +44.7 ($CHCl_3$) (98 mg); $[\alpha]_D^{26}$ −45.2 (*c* 1.58, $CHCl_3$); [θ] −1.79 × 10^3 (293), −2.07 × 10^3 (301) and −1.14 × 10^3 (313sh); ν_{max}/cm^{-1} 1780, 1735, 1235, 1085, 1060 and 1010; δ_H 1.6–2.5 (10 H, m, CH and CH_2), 2.04 (3 H, s, Me) and 5.18 (1 H, octet, *J* 3.6, 1.5 and 1.0, 2-H) (Found: C, 65.75; H, 7.7%).

(1S,5S,8S)-(+)-8-*Acetoxybicyclo*[3.2.1]*octan*-2-*one* **53** (62 mg, 81%) from the monoacetate (−)-**50**, $[\alpha]_D$ −15.8 ($CHCl_3$) (78 mg); $[\alpha]_D^{27}$ +109.6 (*c* 1.18, $CHCl_3$); [θ] +2.49 × 10^3 (288sh), +3.03 × 10^3 (296), +2.79 × 10^3 (306) and +1.45 × 10^3 (317); ν_{max}/cm^{-1} 1740, 1720, 1240, 1150 and 1030; δ_H 1.6–2.6 (9 H, m, 5-H and CH_2), 2.04 (3 H, s, Me), 2.80 (1 H, br s, 1-H) and 4.87 (1 H, s, 8-H) (Found: C, 65.8; H, 7.7%).

(1*R*,2*S*,5*S*)-(−)-2-Acetoxybicyclo[3.2.1]octan-8-one **45** (60 mg, 92%) from the monoacetate (+)-**51**, $[\alpha]_D$ +6.23 ($CHCl_3$) (66 mg); $[\alpha]_D^{24}$ −28.1 (*c* 1.70, $CHCl_3$).

Representative Procedure for Conversion of Keto Acetates into Known Monoacetates.—Conversion of keto acetate (−)-**20** *into* (2S)-(+)-2-*acetoxybicyclo*[2.2.2]*octane* **22**. A mixture of compound (−)-**20**, $[\alpha]_D$ −0.38 ($CHCl_3$) (130 mg, 0.714 mmol), ethane-1,2-dithiol (0.8 cm^3), acetic acid (4 cm^3) and boron trifluoride–diethyl ether (1 cm^3) was stirred for 12 h at room temperature and was then poured into water and extracted with diethyl ether. After usual work-up, silica gel chromatography (diethyl ether as eluent) of the product provided the dithioketal **21** (171 mg, 93%) as a solid, which was heated under reflux with Raney Ni (300 mg) in ethyl acetate (30 cm^3) for 20 h. After removal of Raney Ni, the filtrate was concentrated under reduced pressure. The residue was chromatographed on silica gel (pentane–5% diethyl ether as eluent) gave (2*S*)-(+)-**22** (48 mg, 40%) as an oil, $[\alpha]_D^{26}$ +4.13 (*c* 1.69, $CHCl_3$) {lit.,[11] $[\alpha]_D$ +20 ($CHCl_3$)}.

(2*S*)-(+)-2-Acetoxybicyclo[2.2.1]heptane **9** (247 mg, 88%) from the keto acetate (+)-**7**, $[\alpha]_D$ +1.84 ($CHCl_3$) (307 mg) *via* the dithioketal **8**; $[\alpha]_D^{24}$ +1.24 (*c* 2.02, $CHCl_3$) {lit.,[10] $[\alpha]_D$ +12.0 ($CHCl_3$)}.

(2*S*)-(+)-2-Acetoxybicyclo[2.2.2]octane **22** (113 mg, 91%) from the keto acetate (+)-**27**, $[\alpha]_D$ +19.9 ($CHCl_3$) (160 mg) *via* the dithioketal **28**; $[\alpha]_D^{25}$ +15.9 (*c* 1.80, $CHCl_3$).

(2*S*)-(+)-2-Acetoxybicyclo[2.2.2]octane **22** (121 mg, 85%) from the keto acetate (+)-**37**, $[\alpha]_D$ +95.1 ($CHCl_3$) (170 mg) *via* the dithioketal **38**; $[\alpha]_D^{27}$ +11.1 (*c* 2.20, $CHCl_3$).

(1*S*,2*S*,5*S*)-(+)-2-Acetoxybicyclo[3.2.1]octane **47** (41 mg, 64%) from the keto acetate (−)-**45**, $[\alpha]_D$ −34.6 ($CHCl_3$) (70 mg) *via* the dithioketal **46**; $[\alpha]_D^{25}$ +0.30 (*c* 1.10, $CHCl_3$) {lit.,[11] $[\alpha]_D$ +0.721 ($CHCl_3$)}.

Representative Procedure for Lithium Aluminium Hydride Reduction of Acetates.—Reduction of compound (+)-**17**. To a suspension of $LiAlH_4$ (76 mg, 2.0 mmol) in dry diethyl ether (30 cm^3) was added a solution of the acetate (+)-**17**, $[\alpha]_D$ +6.51 ($CHCl_3$) (122 mg, 0.663 mmol) in dry diethyl ether (30 cm^3) and then the mixture was refluxed for 8 h. After saturated aq. ammonium chloride (0.5 cm^3) had been added to the ice-cooled reaction mixture, an inorganic solid was removed by filtration. The filtrate was dried ($MgSO_4$) and concentrated. Silica gel chromatography (diethyl ether as eluent) of the product gave the diol (1R,2S,4R,5S)-(+)-**15** (60 mg, 64%) as a solid which was not further purified to avoid influence on its optical purity, $[\alpha]_D^{27}$ +8.85 (*c* 1.05, MeOH) (Found: C, 67.4; H, 9.85. $C_8H_{14}O_2$ requires C, 67.57; H, 9.93%). The ee-value (21%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **16**.

(1R,2S,4R,5S)-(−)-*Bicyclo*[2.2.1]*heptane*-2,5-*diol* **3** (150 mg, 87%) as a solid from the monoacetate (+)-**5**, $[\alpha]_D$ +0.81 ($CHCl_3$) (230 mg); $[\alpha]_D^{25}$ −0.73 (*c* 3.10, MeOH) (Found: C, 65.4; H, 9.4. $C_7H_{12}O_2$ requires C, 65.59; H, 9.44%). The ee-value (10%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **4**.

(1S,2S,4S,5S)-(−)-*Bicyclo*[2.2.1]*heptane*-2,5-*diol* **11** (64 mg, 77%) as a solid from the monoacetate (−)-**13**, $[\alpha]_D$ −5.21 ($CHCl_3$) (110 mg); (Found: C, 65.4; H, 9.4%). The ee-value (19%) was confirmed by HPLC analysis of its bis(dichlorobenzoate) **12**.

(1S,2S,4S,5S)-(+)-*Bicyclo*[2.2.2]*octane*-2,5-diol **23** (43 mg, 80%) as a solid from the monoacetate (+)-**25**, $[\alpha]_D$ +19.9 ($CHCl_3$) (70 mg); $[\alpha]_D^{27}$ +44.5 (*c* 1.05, MeOH) (Found: C, 67.4; H, 9.9. $C_8H_{14}O_2$ requires C, 67.57; H, 9.93%). The ee-value (84%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **24**.

(1R,2R,4R,5S)-(+)-*Bicyclo*[2.2.2]*octane*-2,5-*diol* **29** (109 mg, 90%) as a solid from the monoacetate (+)-**31**, $[\alpha]_D$ +1.23 ($CHCl_3$) (157 mg); $[\alpha]_D^{26}$ +2.78 (*c* 1.20, MeOH) (Found: C, 67.5; H, 9.9%). The ee-value (17%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **30**.

(2S,3S)-(−)-*Bicyclo*[2.2.2]*octane*-2,3-*diol* **33** (45 mg, 69%) as a solid from the monoacetate (−)-**35**, $[\alpha]_D$ −65.3 ($CHCl_3$) (84 mg); $[\alpha]_D^{24}$ −5.62 (*c* 1.22, MeOH) (Found: C, 67.5; H, 9.9%). The ee-value (80%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **34**.

(1R,2S,6S,8R)-(−)-*Bicyclo*[3.2.1]*octane*-2,8-*diol* **39** (142 mg, 86%) as a solid from the monoacetate (−)-**41**, $[\alpha]_D$ −48.8 ($CHCl_3$) (214 mg); $[\alpha]_D^{25}$ −4.52 (*c* 2.20, MeOH) (Found: C, 67.6; H, 9.9%). The ee-value (82%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **40**.

(1*S*,2*R*,6*R*,8*S*)-(+)-Bicyclo[3.2.1]octane-2,8-diol **39** (136 mg, 89%) as a solid from the monoacetate (−)-**42**, $[\alpha]_D$ −41.9 ($CHCl_3$) (200 mg); $[\alpha]_D^{25}$ +3.79 (*c* 2.25, MeOH) (Found: C, 67.5; H, 9.9%). The ee-value (68%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **40**.

(1R,2S,5S,8S)-(−)-*Bicyclo*[3.2.1]*octane*-2,8-*diol* **48** (46 mg, 87%) as a solid from the monoacetate (−)-**50**, $[\alpha]_D$ −23.1

($CHCl_3$) (68 mg); $[\alpha]_D^{24}$ +3.68 (*c* 1.10, MeOH) (Found: C, 67.45; H, 9.9%). The ee-value (85%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **49**.

(1*R*,2*S*,5*S*,8*S*)-(−)-Bicyclo[3.2.1]octane-2,8-diol **48** (31 mg, 76%) as a solid from the monoacetate (+)-**51**, $[\alpha]_D$ +7.93 ($CHCl_3$) (53 mg); $[\alpha]_D^{23}$ −2.52 (*c* 1.01, MeOH) (Found: C, 67.5; H, 9.9%).

Lithium Aluminium Hydride Reduction of Diacetates.—(1*S*,2*R*,4*S*,5*R*)-(+)-Bicyclo[2.2.1]heptane-2,5-diol **3** (97 mg, 87%) as a solid from the diacetate (−)-**6**, $[\alpha]_D$ −1.43 ($CHCl_3$) (185 mg); $[\alpha]_D^{24}$ +0.90 (*c* 3.30, MeOH), the ee-value of which was confirmed to be 13% by HPLC analysis of its bis-(phenylcarbamate) **4**.

(1*R*,2*R*,4*R*,5*R*)-(+)-Bicyclo[2.2.1]heptane-2,5-diol **11** (81 mg, 89%) as a solid from the diacetate (+)-**14**, $[\alpha]_D$ +5.60 ($CHCl_3$) (150 mg); the ee-value of which was determined to be 15% by HPLC analysis of its bis(dichlorobenzoate) **12**.

(1*S*,2*R*,4*S*,5*R*)-(−)-Bicyclo[2.2.2]octane-2,5-diol **15** (77 mg, 87%) as a solid from the diacetate (−)-**18**, $[\alpha]_D$ −4.37 ($CHCl_3$) (140 mg); $[\alpha]_D^{27}$ −11.8 (*c* 1.50, MeOH).

(1*R*,2*R*,4*R*,5*R*)-(−)-Bicyclo[2.2.2]octane-2,5-diol **23** (82 mg, 88%) as a solid from the diacetate (−)-**26**, $[\alpha]_D$ −23.3 ($CHCl_3$) (150 mg); $[\alpha]_D^{27}$ −34.9 (*c* 2.20, MeOH).

(1*S*,2*S*,4*S*,5*R*)-(−)-Bicyclo[2.2.2]octane-2,5-diol **29** (153 mg, 87%) as a solid from the diacetate (−)-**32**, $[\alpha]_D$ −1.48 ($CHCl_3$) (280 mg); $[\alpha]_D^{24}$ −2.76 (*c* 1.80, MeOH).

(2*S*,3*S*)-(−)-Bicyclo[2.2.2]octane-2,3-diol **33** (170 mg, 88%) as a solid from the diacetate (+)-**36**, $[\alpha]_D$ +14.6 ($CHCl_3$) (193 mg); $[\alpha]_D^{24}$ −5.98 (*c* 2.50, MeOH).

(1*R*,2*S*,6*S*,8*R*)-(−)-Bicyclo[3.2.1]octane-2,8-diol **39** (75 mg, 71%) as a solid from the diacetate (+)-**43**, $[\alpha]_D$ +8.58 ($CHCl_3$) (167 mg); $[\alpha]_D^{27}$ −0.67 (*c* 2.20, MeOH). The ee-value (12%) was confirmed by HPLC analysis of its bis(phenylcarbamate) **40**.

(1*R*,2*S*,5*S*,8*S*)-(−)-Bicyclo[3.2.1]octane-2,8-diol **48** (90 mg, 80%) as a solid from the diacetate (+)-**52**, $[\alpha]_D$ +4.07 ($CHCl_3$) (180 mg); $[\alpha]_D^{26}$ −2.06 (*c* 1.50, MeOH).

Representative Procedure for Preparation of Bis(phenylcarbamate)s.—exo,exo-2,5-*Bis(phenylcarbamoyl)bicyclo*[2.2.2]-*octane* **16**. A mixture of the diol (−)-**15**, $[\alpha]_D$ −11.8 (MeOH) (20 mg, 0.14 mmol), phenyl isocyanate (37 mg, 0.31 mmol), benzene (0.5 cm^3), and one drop of pyridine was stirred for 24 h at room temperature. Removal of the volatile materials under reduced pressure gave a brown solid, which was not further purified, and its ee-value was determined to be 26% on HPLC (ethanol–10% hexane as eluent).

Representative Procedure for Oxidation of Diols.—(+)-*Bicyclo*[2.2.1]*heptane*-2,5-*dione* **10**. To a solution of the diol (−)-**3**, $[\alpha]_D$ −0.73 (MeOH) (100 mg, 0.781 mmol) in acetone (10 cm^3) was added an excess of Jones reagent at 0–5 °C and then the mixture was stirred for 3 h at the same temperature. After similar work-up to that described for the oxidation of compound (+)-**5**, silica gel chromatography [hexane–diethyl ether (1:1) as eluent] gave the dione (+)-**10** (63 mg, 65%) as a solid [lit.,[7] (±)-**10**; m.p. 141.5—143 °C], $[\alpha]_D^{26}$ +0.33 (*c* 4.13, $CHCl_3$); [θ] -1.92×10^2 (298sh), -2.27×10^2 (308) and -1.91×10^2 (318) (Found: C, 67.6; H, 6.5. $C_7H_8O_2$ requires C, 67.73; H, 6.50%).

(1*S*,4*S*)-(−)-Bicyclo[2.2.1]heptane-2,5-dione **10** (94 mg, 63%) from the diol (−)-**11**, $[\alpha]_D$ −1.31 (MeOH) (155 mg); $[\alpha]_D^{23}$ −0.87 (*c* 3.13, $CHCl_3$).

(1R,4R)-(−)-*Bicyclo*[2.2.2]*octane*-2,5-*dione* **19** (38 mg, 76%) as a solid [lit.,[8] (±)-**9**; m.p. 205–206 °C] from the diol (+)-**15**, $[\alpha]_D$ −29.1 (MeOH) (52 mg); $[\alpha]_D^{23}$ −25.9 (*c* 0.590, $CHCl_3$); [θ] -6.41×10^2 (293), -7.34×10^2 (298), -6.17×10^2 (308) and -2.68×10^2 (320sh); ν_{max}/cm^{-1} 1718 and 1680 (Found: C, 69.4; H, 7.3. $C_8H_{10}O_2$ requires C, 69.54; H, 7.30%).

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